

Figure 7-4. Cross Section of a Fluidized Bed Furnace

Source: Reference 198.

general configurations can be distinguished on the basis of how the fluidizing air is injected into the furnace. In the “hot windbox” design, the combustion air is first preheated by passing through a heat exchanger, where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace from a cold windbox.

Partially dewatered sludge is fed into the lower portion of the furnace. Air injected through the tuyeres at a pressure of 3 to 5 pounds per square inch gauge (20 to 35 kilopascals), simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 1,400 to 1,700°F (750 to 925°C) are maintained in the bed. As the sludge burns, fine ash particles are carried out the top of the furnace. Some sand is also removed in the air stream and must be replaced at regular intervals.

Combustion of the sludge occurs in two zones. Within the sand bed itself (the first zone), evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is rapidly raised. In the freeboard area (the second zone), the remaining free carbon and combustible gases are burned. The second zone functions essentially as an afterburner.

Fluidization achieves nearly ideal mixing between the sludge and the combustion air, and the turbulence facilitates the transfer of heat from the hot sand to the sludge. The most noticeable impact of the better burning atmosphere provided by an FBC is seen in the limited amount of excess air required for complete combustion of the sludge. Typically, FBCs can achieve complete combustion with 20 to 50 percent excess air, about half the excess air required by MHFs. As a consequence, FBCs generally have lower fuel requirements compared to MHFs.

Electric Infrared Incinerators

Electric infrared incinerators consist of a horizontally oriented, insulated furnace. A woven wire belt conveyor extends the length of the furnace and infrared heating

elements are located in the roof above the conveyor belt. Combustion air is preheated by the flue gases and is injected into the discharge end of the furnace. Electric infrared incinerators consist of a number of prefabricated modules that can be linked together to provide the necessary furnace length. A cross-section of an electric furnace is shown in Figure 7-5.¹⁹⁸

The dewatered sludge cake is conveyed into one end of the incinerator. An internal roller mechanism levels the sludge into a continuous layer approximately 1 inch thick across the width of the belt. The sludge is sequentially dried and then burned as it moves beneath the infrared heating elements. Ash is discharged into a hopper at the opposite end of the furnace. The preheated combustion air enters the furnace above the ash hopper and is further heated by the outgoing ash. The direction of air flow is countercurrent to the movement of the sludge along the conveyor. Exhaust gases leave the furnace at the feed end. Excess air rates vary from 20 to 70 percent.

Other Technologies

A number of other technologies have been used for incineration of sewage sludge, including cyclonic reactors, rotary kilns, and wet oxidation reactors. These processes are not in widespread use in the United States and are discussed only briefly.

The cyclonic reactor is designed for small-capacity applications and consists of a vertical cylindrical chamber that is lined with refractory. Preheated combustion air is introduced into the chamber tangentially at high velocities. The sludge is sprayed radially toward the hot refractory walls. Combustion is rapid, such that the residence time of the sludge in the chamber is on the order of 10 seconds. The ash is removed with the flue gases.

Rotary kilns are also generally used for small capacity applications. The kiln is inclined slightly from the horizontal plane, with the upper end receiving both the sludge feed and the combustion air. A burner is located at the lower end of the kiln. The circumference of

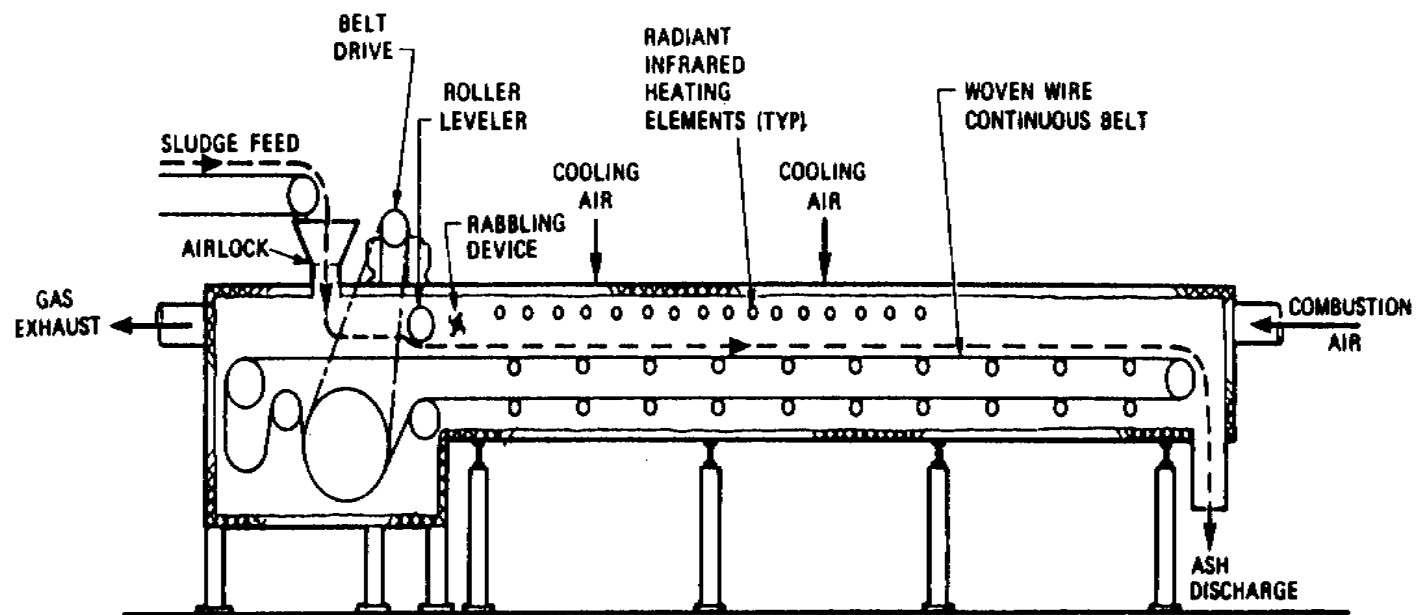


Figure 7-5. Cross Section of an Electric Infrared Furnace

Source: Reference 198.

the kiln rotates at a speed of about 6 inches per second. Ash is deposited into a hopper located below the burner.

The wet oxidation process is not strictly one of incineration; it instead utilizes oxidation at elevated temperature and pressure in the presence of water (flameless combustion). Thickened sludge, at about 6-percent solids, is first ground and mixed with a stoichiometric amount of compressed air. The sludge/air mixture is then circulated through a series of heat exchangers before entering a pressurized reactor. The temperature of the reactor is held between 350 and 600°F (175 and 315°C). The pressure is normally 1,000 to 1,800 pounds per square inch grade (7,000 to 12,500 kilopascals). Steam is usually used for auxiliary heat. The water and resulting ash are circulated out the reactor and are separated in a tank or lagoon. The liquid phase is recycled to the treatment plant. Off-gases must be treated to eliminate odors.

Co-Incineration and Co-Firing

Wastewater treatment plant sludge generally has a high water content and, in some cases, fairly high levels of inert materials. As a result, the net fuel value of sludge is often low. If sludge is combined with other combustible materials in a co-incineration scheme, a furnace feed can be created that has both a low water concentration and a heat value high enough to sustain combustion with little or no supplemental fuel. Virtually any material that can be burned can be combined with sludge in a co-incineration process. Common materials for co-incineration are coal, municipal solid waste (MSW), wood waste, and agricultural waste.

There are two basic approaches to combusting sludge with MSW: (1) use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit, and (2) use of sludge combustion technology by adding processed MSW as a supplemental fuel to the sludge furnace. With the latter, MSW is processed by removing noncombustibles, shredding, air classifying, and screening. Waste that is more finely

processed is less likely to cause problems such as severe erosion of the hearths, poor temperature control, and refractory failures.

7.2.2 Benzene Emissions from Sewage Sludge Incineration

Emission factors associated with MHFs and FBCs are provided in Table 7-2.¹⁹⁷ This table provides a comparison of benzene emissions based on no control and control with various PM control devices and an afterburner. However, these emission factors do not reflect the effect of increased operating temperature on reducing benzene emissions. As discussed in Section 7.2.3, increasing the combustion temperature facilitates more complete combustion of organics, resulting in lower benzene emissions. It was not possible in this study to compare the combustor operating conditions of all SSIs for which emissions test data were available to develop the emission factors in Table 7-2.¹⁹⁷ As a result, it was not possible to reflect the effect of combustion temperature on benzene emissions. The emission factors for MHFs presented in Table 7-2 are based on test data of combustors operated at a variety of combustion temperatures in the primary combustion hearths (1,100 to 1,700 °F [600 to 930 °C]).

Using emissions test data for one sewage sludge combustion facility, it was possible to demonstrate the benzene emission reduction achieved with the practice of increasing operating temperature versus utilizing an afterburner or a scrubber. This comparison is provided in Table 7-3.¹⁹⁹ The emissions test data for the one facility used to develop the emission factors presented in Table 7-3 are also averaged into the emission factors presented in Table 7-2.

7.2.3 Control Technologies for Sewage Sludge Incinerators^{197,198}

Control of benzene emissions from SSIs is achieved primarily by promoting complete combustion by following GCP. The general conditions of GCP are summarized in Section 7.1.3. As with MWIs, failure to achieve complete combustion of organic materials evolved from the waste can result in emissions of a variety of organic compounds, including

TABLE 7-2. SUMMARY OF EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATION

SCC	Emission Source	Control Device	Emission Factor lb/ton (g/Mg) ^a	Factor Rating
5-01-005-15	MHF	Uncontrolled	1.2×10^{-2} (5.8)	D
		Cyclone/venturi scrubbers	7.0×10^{-4} (3.5×10^{-1})	E
		Venturi scrubber	2.8×10^{-2} (1.4)	E
		Venturi/impingement scrubbers	1.3×10^{-2} (6.3)	D
		Venturi/impingement scrubbers and afterburner	3.4×10^{-4} (1.7×10^{-1})	E
5-01-005-16	FBC	Venturi/impingement scrubbers	4.0×10^{-4} (2.0×10^{-1})	E

Source: Reference 197.

^a Emission factors are in lb (g) of benzene emitted per ton (Mg) of dry sludge feed.

MHF = multiple hearth furnace.

FBC = fluidized bed combustor.

TABLE 7-3. SUMMARY OF EMISSION FACTORS FOR ONE SEWAGE SLUDGE INCINERATION FACILITY UTILIZING A MULTIPLE HEARTH FURNACE

SCC	Emission Source	Control Device/Method	Emission Factor lb/ton (g/Mg) ^a	Efficiency Percent	Factor Rating
5-01-005-15	Incinerator	Uncontrolled ^b	1.73×10^{-2} (8.61)	--	D
		Venturi/Impingement Scrubbers ^b	1.34×10^{-2} (6.66)	23	D
		Elevated Operating Temperature ^c	2.65×10^{-3} (1.32)	85	D
		Elevated Operating Temperature/Afterburner ^c	1.41×10^{-3} (7.02×10^{-1})	92	D
		Elevated Operating Temperature/ Afterburner/Venturi and Impingement Scrubbers ^c	3.35×10^{-4} (1.67×10^{-1})	98	D

Source: Reference 199.

^a Emission factors are in lb (g) of benzene emitted per ton (Mg) of dry sludge feed.

^b Furnace operated at “normal” operating temperature of, on average, 1350 °F (730 °C).

^c Furnace operated at a higher than “normal” operating temperature of, on average, 1600 °F (870 °C).

benzene, and adequate oxygen, temperature, residence time, and turbulence will generally minimize emissions of most organics.

Many SSIs have greater variability in their organic emissions than do other waste incinerators because, on average, sewage sludge has a high moisture content and the moisture content can vary widely during operation.²⁰⁰

Additional reductions in benzene emissions may be achieved by utilizing PM control devices; however, it is not always the case that a PM control device will reduce benzene emissions. In some cases, the incinerator operating conditions (e.g., combustion temperature and temperature at the air pollution control device) may affect the performance of scrubbers.¹⁹⁹ The types of existing SSI PM controls range from low-pressure-drop spray towers and wet cyclones to higher-pressure-drop venturi scrubbers and venturi/impingement tray scrubber combinations. A few ESPs and baghouses are employed, primarily where sludge is co-fired with MSW.

The most widely used PM control device applied to an MHF is the impingement tray scrubber. Older units use the tray scrubber alone and combination venturi/impingement tray scrubbers are widely applied to newer MHFs and some FBCs. Most electric incinerators and some FBCs use venturi scrubbers only. As indicated in Table 7-3, venturi/impingement tray scrubbers have been demonstrated to reduce benzene emissions from SSIs.

A schematic diagram of a typical combination venturi/impingement tray scrubber is presented in Figure 7-6.¹⁹⁸ Hot gas exits the incinerator and enters the precooling or quench section of the scrubber. Spray nozzles in the quench section cool the incoming gas, and the quenched gas then enters the venturi section of the control device.

Venturi water is usually pumped into an inlet weir above the quencher. The venturi water enters the scrubber above the throat, completely flooding the throat. Turbulence created by high gas velocity in the converging throat section deflects some of the water

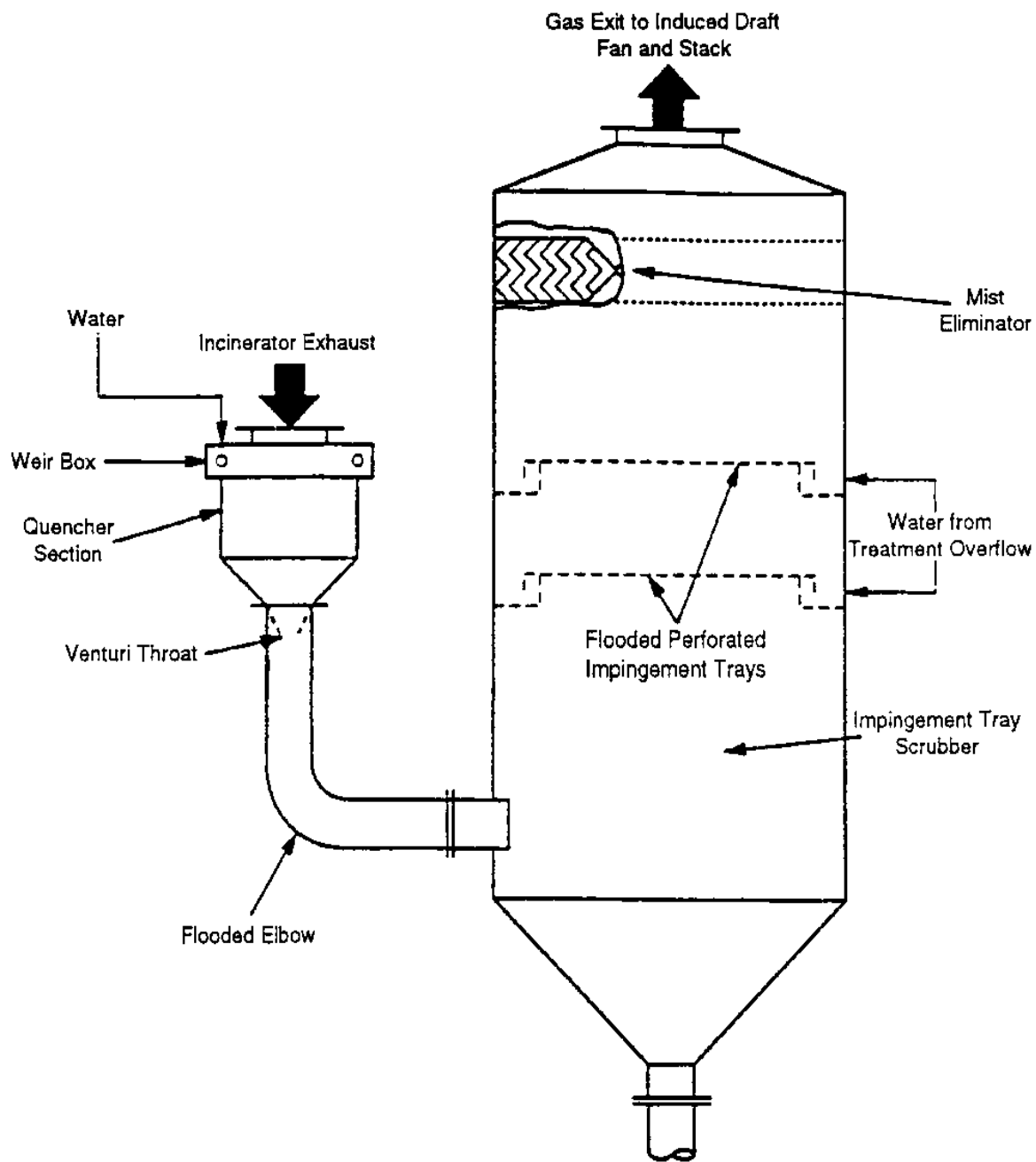


Figure 7-6. Venturi/Impingement Tray Scrubber

Source: Reference 198.